

# The quasi-biennial periodicity as a window on the solar magnetic dynamo configuration

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## ABSTRACT

Manifestations of the solar magnetic activity through periodicities of about 11 and 2 years are now clearly seen in all solar activity indices. In this paper, we add information about the mechanism driving the 2 year period by studying the time and latitudinal properties of acoustic modes that are sensitive probes of the subsurface layers. We use almost 17 years of high quality resolved data provided by the Global Oscillation Network Group (GONG) to investigate the solar cycle changes in  $p$ -mode frequencies for spherical degrees  $\ell$  from 0 to 120 and  $1600 \mu\text{Hz} \leq \nu \leq 3500 \mu\text{Hz}$ . For both periodic components of solar activity, we locate the origin of the frequency shift in the subsurface layers and put in evidence for a sudden enhancement in amplitude just in the last few hundred kilometers. We also show that, in both cases, the size of the shift increases towards equatorial latitudes and from minimum to maximum of solar activity, but, in agreement with previous findings, the quasi-biennial periodicity (QBP) causes a weaker shift in mode frequencies and a slower enhancement than the one caused by the 11 year cycle. We compare our observational findings with the features predicted by different models that try to explain the origin of this QBP and conclude that the observed properties could result from the beating between a dipole and quadrupole magnetic configuration of the dynamo.

*Subject headings:* Sun: helioseismology - activity - dynamo

## 1. Introduction

Long term time series open a new perspective in the study of stellar activity cycles as they revealed the existence of a complex scenario. In fact stars can give rise to all types of periodicities from none to multiple cycles (Baliunas et al. 1995; Brandenburg et al. 1998; Messina & Guinan 2002; Oláh & Strassmeier 2002; Böhm-Vitense 2007). A beating between dipolar and quadrupolar components of dynamo's magnetic configuration might explain the apparent multiple periods observed in some stars (Moss 2004; Fluri & Berdyugina 2004; Moss 2008).

The Sun also show several periodicities on different time scales longer and shorter than the sunspot cycle (Bai 2003; Usoskin et al. 2007; Kolláth & Oláh 2009). The quasi-biennial periodicity (QBP) has recently received a great deal of interest, as it appears in all solar activity proxies. Its amplitude is particularly strong near the solar maximum, although it doesn't seem to characterize every solar cycle (Krivova & Solanki 2002; Vecchio & Carbone 2008; Vecchio et al. 2009). Several mechanisms have been proposed so far to explain the origin of the QBP like a second dynamo mechanism generated by the strong rotational shear extended from the surface down to

5% below it (Benevolenskaja 1998a,b) or the instability of magnetic Rossby waves in the tachocline (Zaqarashvili et al. 2010, 2011).

Recently the discovery of the shortest cycle so far measured has also been reported on solar type star (Metcalf et al. 2010). This phenomenon could be related to the mid-timescale magnetic variations recently identified in HD 49933 from asteroseismic observations (García et al. 2010) and to the solar QBP clearly visible in helioseismic measurements of low degree modes (Broomhall et al. 2009; Salabert et al. 2010; Simoniello et al. 2012).

The helioseismic changes in  $p$ -mode parameters are strongly correlated to the cyclic behavior of solar magnetic activity. The mode amplitude is linked to the excitation of the mode and its changes is due to mode conversion (Simoniello et al. 2010). The mode frequency shift results from the effect of the magnetic field on the acoustic cavity extension. The seismic signatures of the solar QBP have been interpreted as the result of a second dynamo mechanism by Fletcher et al. (2010) and Broomhall et al. (2012). Jain et al. (2011) and Simoniello et al. (2012) discussed other scenarios such as the signature of the relic solar magnetic field, different dynamo modes or a separate mechanism from the main dynamo.

With the hope to better understand the origin of the solar QBP, we investigate the temporal variation in  $p$ -mode frequency of low and intermediate degree modes over solar cycle 23 and ascending phase of solar cycle 24 using data provided by the Global Oscillation Network Group. We perform a detailed study of the 2 yr signal extracted by the total shifts by investigating its properties as function of mode frequency, penetration depth and latitude. When scaled by their mode inertia all the modes with different degree vary in the same way, so looking simultaneously at numerous modes within selected frequency bands should let the smaller effect of time variabilities emerging. We will afterwards confine our study in the subsurface layers selecting only modes whose lower turning point is above 0.90 solar radius and by tuning the ratio  $\frac{m}{\ell}$ , we will select modes sensitive to specific latitudes. The characterization of the shift with frequency, penetration depth and latitude will provide the chance to verify whether or not the origin of the shift over the 2 yr cycles could differ from the one induced over the 11 yr cycle. Finally the properties of the 2 yr signal will be also compared with the features predicted by different models and this should allow us to gain information

on the mechanism driving the cyclic behaviour of solar magnetic activity.

## 2. Data analysis

### 2.1. Mode frequency determination

The Global Oscillation Network Group (GONG) provides nearly continuous and stable velocity images of the Sun since May 1995. It consists of six instruments deployed worldwide, based on a Michelson interferometer using the Ni line at 676.8nm. Mode parameters (frequency, full width and amplitude) for each  $(n, \ell, m)$  are estimated up to  $\ell=150$  by applying the standard GONG analysis (Anderson et al. 1990). The peak-fitting algorithm has two types of criteria to judge the quality of the fit to a mode (Hill et al. 1998) and based on these quality flags, we removed few outliers from the analysis. The individual  $p$ -mode parameters are afterwards made publicly available (<http://gong2.nso.edu/archive/>). In this work we analyze the temporal variations of  $p$ -mode frequencies covering almost 17 years of observations starting from May 1995 up to January 2012.

### 2.2. Central frequency of the multiplets

The spatial structure of the acoustic modes in the Sun can be described by associated Legendre functions  $P_\ell^m(x)$ , where  $\ell$  is the degree,  $m$  is the azimuthal order, running from  $-\ell$  to  $\ell$ ,  $x$  is the cosine of the colatitude  $\theta$ . The degeneracy among the modes of the same  $\ell$  and  $m$  is broken by rotation and asphericity. The labelling of a mode is completed by the radial order  $n$  (number of radial intersections or harmonics). The frequencies of a mode of specific  $n, \ell$  multiplet are given using the following polynomial expansion:

$$\nu_{n,\ell,m} = \nu_{n,\ell} + \sum a_j(n, \ell) P_j^\ell(m) \quad (1)$$

where the basic functions are polynomials related to the Clebsch-Gordan coefficients  $C_{j0\ell m}^{\ell,m}$  (Ritzwoller & Lavelle 1991) by

$$P_j^\ell(m) = \frac{\ell \sqrt{(2\ell-1)!(2\ell+j+1)!}}{(2\ell)! \sqrt{(2\ell+1)}} C_{j0\ell m}^{\ell,m} \quad (2)$$

The frequency  $\nu_{n\ell}$  is the so-called central frequency of the multiplet and we will also use this parameter as it provides a measure of the global activity of the Sun.

### 2.3. Frequency shift determination

In this work we look for temporal variations in  $p$ -mode frequencies caused by changes in magnetic activity levels. Within this context the frequency shift can be defined as the difference between the frequencies of the corresponding modes observed at different epochs and reference values taken as average over the minimum phase of solar activity ( $\delta\nu \equiv \nu_i - \nu(B_0)$ ) or as the difference between the mode frequency at certain date and its temporal mean ( $\delta\nu_i \equiv \nu_i(B) - \bar{\nu}_i$ ) (Howe et al. 2002). We choose the first approach as it provides the advantage to direct compare the shift with other publications, because doesn't depend on the inclusion of new data sets. Since the frequency shifts has a well-known dependency on frequency and mode inertia (Jain et al. 2001), we consider only those modes that are present in all data sets and the shifts are scaled by the mode inertia (Christensen-Dalsgaard & Berthomieu 1991). The mean frequency shifts is calculated from the following relation:

$$\delta\nu(t) = \frac{\sum_{n,\ell,m} \frac{Q_{n,\ell}}{\sigma_{n,\ell,m}^2} \delta\nu(t)}{\sum_{n,\ell,m} \frac{Q_{n,\ell}}{\sigma_{n,\ell,m}^2}}. \quad (3)$$

The weighted averages of these frequency shifts were then calculated in two different frequency bands:

1. low frequency band  $1600 \mu\text{Hz} \leq \nu \leq 2500 \mu\text{Hz}$ ;
2. high frequency band  $2500 \mu\text{Hz} \leq \nu \leq 3500 \mu\text{Hz}$ .

This frequency dependence analysis will tell us to which depths the 2 year signal is the most sensitive. In fact the mode frequency determines the position of the upper turning point (UTP) of the waves and as the mode frequency increases as the UTP approaches the solar surface. Seismic observations over the 11 year cycle have already shown that, the increase in the magnitude of the shift is predominantly a subsurface phenomenon as it strongly increases in the upper few hundred kilometers (Chaplin et al. 2001).

## 3. Analysis of the QBP signatures in $p$ -mode frequency shift

### 3.1. Frequency dependence

We investigate the solar cycle changes in  $p$ -mode central frequency averaged over spherical degree  $\ell=0$ -120. In order to extract the quasi-biennial signal

from the total shifts, we subtracted the 11 year envelope by using a boxcar average of 2.5 year width (Fletcher et al. 2010). Fig. 1 compares the temporal changes in  $p$ -mode frequency in the two frequency bands over solar cycle 23 (top panel) and more specifically for the 2-year period (bottom panel). The error in shifts are of the order of  $10^{-3} \mu\text{Hz}$  for both frequency bands. The presence of a quasi-biennial modulation is clearly visible in both frequency bands and over the whole period of observation. There are several interesting features to underline in the magnitude of the shift over the 2 year cycle and that one can compare to previous studies on low degree modes:

- it is rather weak;
- it increases by a factor of  $\approx 3$  from low to high frequency band. This enhancement is smoother compared to the stronger increase over the 11 yr cycle;
- it becomes faint over the descending phase of solar cycle 23 and the low and high frequency band are identical in this descending phase.

The other interesting feature is that over the ascending phase of solar cycle 23 the signal is larger in the high frequency band, while this does not occur over ascending phase of solar cycle 24. This might imply that the ongoing cycle 24 will be weaker compared to solar cycle 23.

### 3.2. Assessing the significance

We investigate the significance of the QBP signal in  $p$ -mode central frequency averaged over spherical degree  $\ell=0$ -120 and in the two frequency bands, by applying the wavelet analysis developed by Torrence & Compo (1998). The upper panels of Fig. 2 show the temporal evolution of  $p$ -mode frequency shifts over the period 1996-2012, while the lower panels identify periods in which the signal gets 90% confidence level for both frequency bands. This occurs during periods around the solar maximum (1998-2004) with a significant periodicity of about  $T = 2$  years. This shorter cyclic component characterizes different phases of solar magnetic activity, in contrast with activity proxies where the QBP signal is mainly prominent over periods coinciding with solar maximum. This peculiar feature seems to further confirm the persistent nature of the QBP signal, in agreement with previous findings based on the analysis of low degree modes (Simoniello et al. 2012).

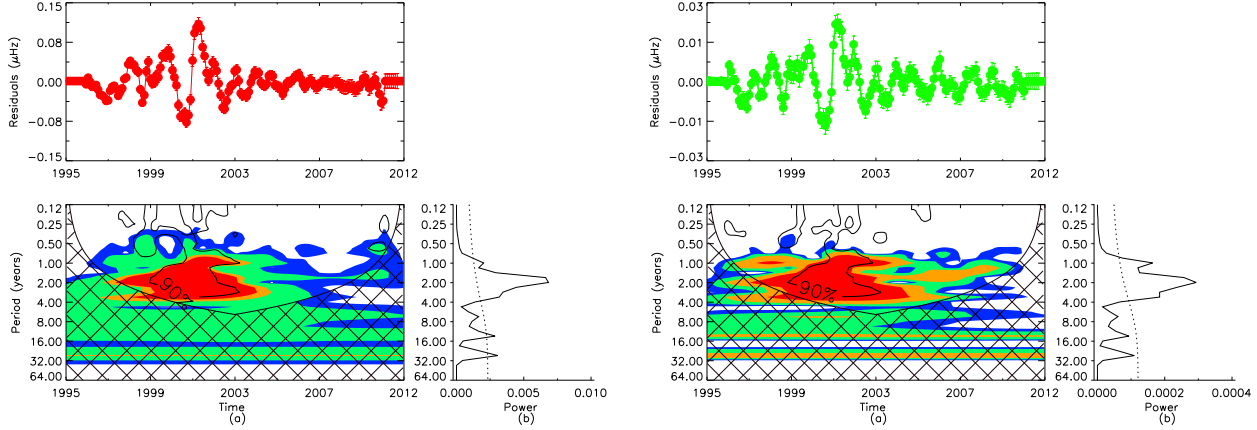


Fig. 2.— Top panels: Temporal evolution of  $p$ -mode frequency shifts averaged over  $\ell=0,120$  spherical degree and in the high (left panel) and low (right panel) frequency bands. (a) The local wavelet power spectrum. White represent areas of little power, red those with the largest power. Solid rings identify areas at certain power level over time and only those that achieved 90% confidence level are labelled. Areas outside the cone of influence are doubtful. (b) Global wavelet power spectrum. The dotted line are the 90% of confidence level.

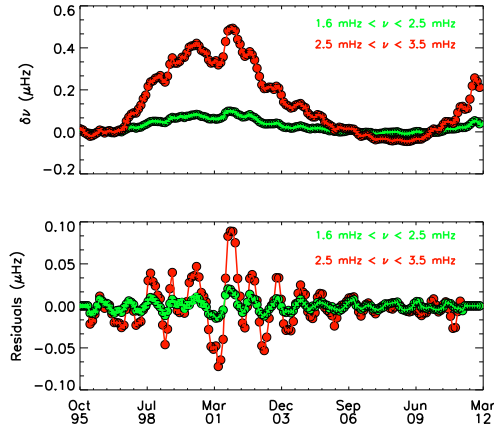


Fig. 1.— The frequency dependence of the shift in the low (green) and high frequency band (red) over solar cycle 23 (upper panel) and the residual 2 yr cycles (lower panel).

This finding is important to advance in dynamo theories that already take into account both periodic components of solar magnetic activity. The understanding of the 2 year signal might insert further constraints in these models.

### 3.3. Depth and latitudinal dependence

The  $p$ -mode spatial configuration can be described by spherical harmonics with each mode characterized by its spherical harmonic degree  $\ell$  and azimuthal order  $m$ . The spherical degree defines the penetration depth through the following relation (Christensen-Dalsgaard & Berthomieu 1991):

$$r_t = \frac{c(r_t) \sqrt{\ell(\ell+1)}}{2\pi\nu} \quad (4)$$

where  $c$  is the sound speed and  $r_t$  is the LTP radius. A higher value of  $\frac{\nu}{\sqrt{\ell(\ell+1)}}$  denotes a smaller value of  $r_t$  and hence a greater depth. We carried out a depth dependence analysis in four different regions of the Sun's interior (core, radiative zone, tachocline and convection zone) to verify that the shifts we discuss is independently confined. Then we used the ratio  $\frac{\nu}{\sqrt{\ell(\ell+1)}}$  to select only the modes having their LTP between  $0.90 \leq \frac{r_t}{R} \leq 1$  solar radius. This would verify the frequency dependence of the shift in the subsurface layers and exclude different behavior over the two cycles due, for example, to the presence of a second dynamo mechanism. Simultaneously we used the ratio  $\frac{m}{\ell}$  to select the acoustic modes more sensitive to lower or to higher latitudes. We decided to select three different latitudinal bands corresponding to equatorial latitudes ( $0^\circ \leq \theta \leq 30^\circ$ ), mid latitudes ( $30^\circ \leq \theta \leq 60^\circ$ ) and high latitudes ( $60^\circ \leq \theta \leq 90^\circ$ ). Some authors have

speculated that the QBP signal might be induced by a second dynamo mechanism located at 0.95 solar radius (Benevolenskaja 1998a,b). It is known that the strong shear present in the subsurface layers increases towards latitudes higher than  $60^\circ$  (Schou et al. 1998). If this layer is acting as a second dynamo mechanism and it is causing the QBP, we might find an increase of the 2 yr signal at higher latitudes. Fig. 3 shows the changes during the solar cycle 23 as function of latitude for three ranges:

The figures present several interesting features:

- the magnitude of the shift decreases with increasing latitudes over both periodic components characterizing solar magnetic activity. This might indicate that the larger magnitude of the signal at equatorial latitudes could be due to the presence of the strong toroidal fields located between  $-45^\circ \leq \theta \leq 45^\circ$  (de Toma et al. 2000) during the course of the 11 yr cycle;
- the size of the shift is larger at equatorial latitudes and over periods coinciding with solar maximum at all latitudes and over both periodic components;
- the 11 yr envelope over the 2 yr cycle is clearly visible at all latitudes.

All these features clearly show that the QBP signal is highly coupled with the main dynamo driving the 11 yr cycle.

## 4. Origin of the observed frequency shift

### 4.1. Magnitude of the shift versus the subsurface layers

The characterization of the shift with frequency, depth and latitude over the 11 and 2 yr cycles has shown differences in the enhancement rate of the magnitude of the shift. We now attempt to provide an explanation for it. Fig. 4 shows the frequency dependence of the frequency shifts taken over the months 08/08/2001-19/10/2001 (top panels). This period corresponds to the maximum amplitude of the shift for both component of solar activity cycles. It shows that the enhanced amplitude follows an exponential behavior over solar cycle 23, in agreement with previous findings, and a slower enhancement rate over the 2 yr cycle. The bottom panels in Fig. 4 shows the magnitude of the shift as a function of the position of the upper turning point. Those values have been calculated

from model S of Christensen Dalsgaard (Chaplin et al. 2001). A sudden increase in the size of the shift is clearly visible in the last few hundred kilometers beneath the solar surface for both periodic components, although it is reduced over the 2 yr period. The acoustic time of the modes is larger in these layers as the sound speed is smaller so any change of magnetic field strength in these layers is amplified.

### 4.2. Variation of $\beta$ in the subsurface layers

The solar magnetic signature along the solar cycle 23 has been extracted from the even-order splitting coefficients of the high degree acoustic modes observed with MDI at respectively 0.996 and 0.999  $R_\odot$ . This study shows that poloidal and toroidal magnetic field strengths decrease toward the solar surface (Baldner et al. 2009). Fig. 5 shows the strength of these two magnetic field components along the solar cycle 23 and also deduces the 2 year cycle components at  $\frac{r_i}{R} = 0.999$  and  $\frac{r_e}{R} = 0.996$ . Signatures of the 2 year signal reach 90% of confidence level around the solar maximum (1998-2004) with a period of 2.3 years for both component. This periodicity agrees reasonably well with our findings. We now attempt to interpret our findings by taking into account the magnetic field strength behavior in the subsurface layers and the increase of the amplitude of the modes near the solar surface. We have been misleading if one has deduced that the magnetic field strength should also increase. This is not the appropriate interpretation. In the Sun's interior the  $\beta = \frac{P_{gas}}{P_{mag}} \gg 1$ , as the gas pressure is extremely large compared to the magnetic pressure. Only very close to the surface this value becomes smaller (Kosovichev 2007). The gas pressure undergoes a strong decay near the surface, while the magnetic pressure, over the same range of depths, undergoes a slower decay ( $B^2$ ). As a consequence,  $\beta$  reduces dramatically at the vicinity of the surface, so the magnetic pressure plays a direct role on the mode frequency in very close layers near the surface, inciting consequently the observed shift. The rapid enhancement in the size of the shift is, therefore, a combination of the  $\beta$  ratio and longer acoustic time of the modes in these layers. The reduced size of enhancement over the 2 yr cycle may be interpreted in terms of magnetic field strength or topology (see Sec 6.3).



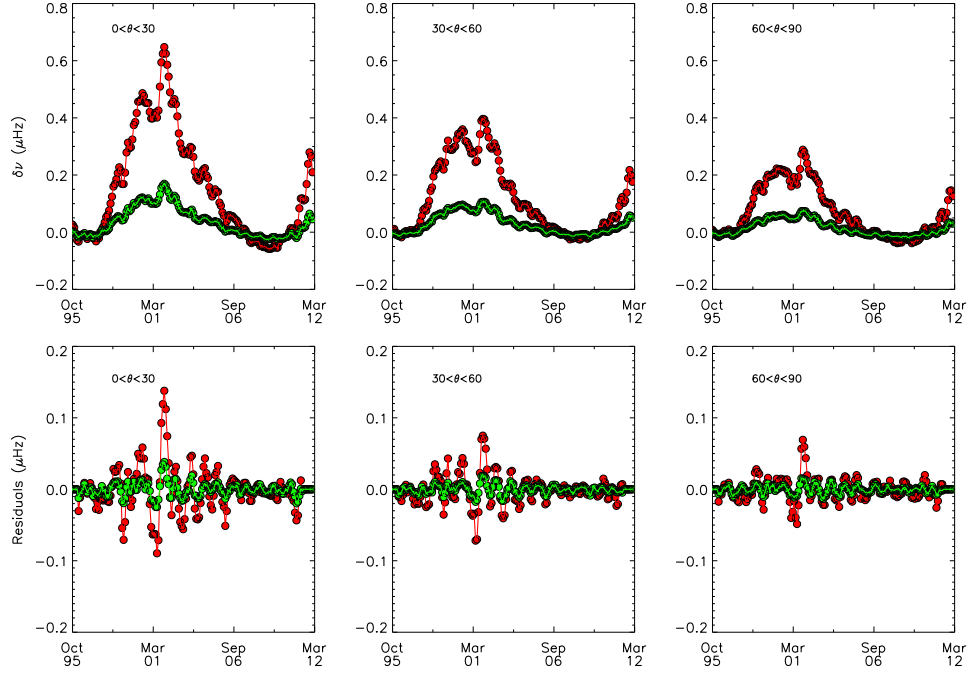


Fig. 3.— The latitudinal dependence of  $p$ -mode frequency shift in the subsurface layer. The color legend is the same as in Fig.1.

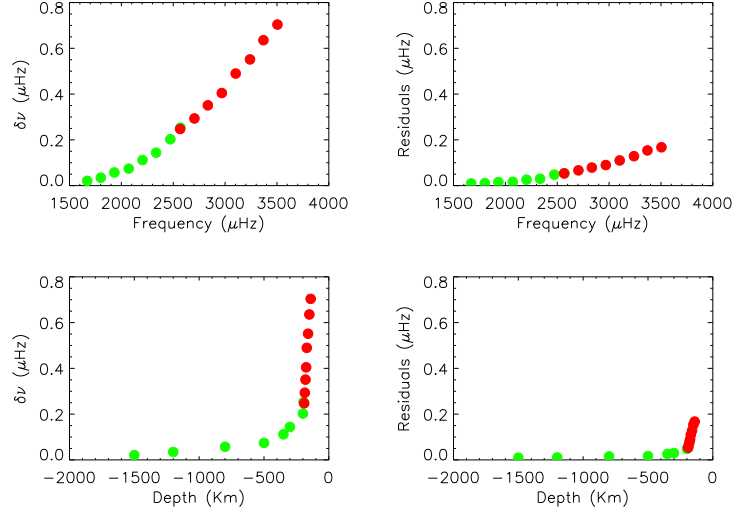


Fig. 4.— The top panels show the frequency dependence of the shifts obtained at the maximum of the solar cycle over the months 08/08/2001-19/10/2001 for the 11 year (left panels) and the 2 year cycles (right panels). The bottom panels show the same amplitudes of the shifts as function of depth from the surface of the Sun. The color legend is the same as in Fig.1.

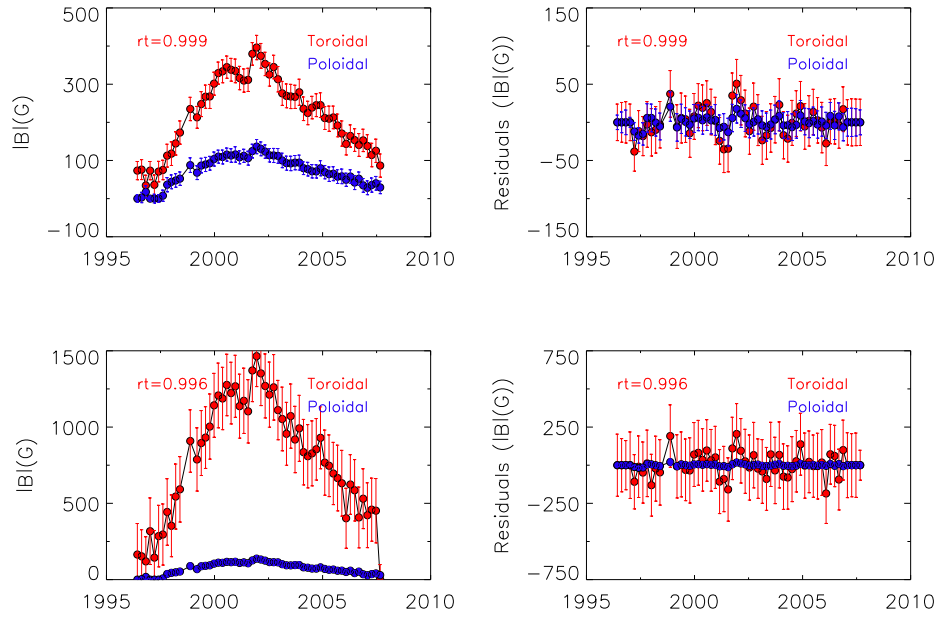


Fig. 5.— Decomposition of the magnetic field strength in poloidal and toroidal fields along solar cycle 23 (left panels) based on Baldner et al. (2009). Extraction of the components for the 2 year cycle (right panels) at 0.999 (upper panels) and 0.996 solar radius (lower panels).

### 4.3. Magnetic field in the subsurface layers from 3D simulation

The order of magnitude of the magnetic field deduced from splitting values of the sub surface layers (Baldner et al. 2009) give a first insight on what phenomenon can influence the shifts that is discussed in this paper. In parallel to this classical approach, dedicated to secular 1D models of the Sun in agreement with deeper helioseismic observations, 3D hydro and magnetohydrodynamic simulations have been developed by Stein & Nordlund (1998) through the code STAGGER. They have shown that the order of magnitude of the turbulence pressure represents about 10% of the gas pressure in the simulations of the subsurface layers of the Sun (Nordlund & Stein 2000). Even more interestingly, they have put in evidence that this turbulent term concerns a larger region than previously thought, typically at least 1000 km (Rosenthal et al. 1999). Magnetohydrodynamical simulations of 48 Mm large and 20 Mm deep have been performed recently, using an horizontal magnetic field chosen at the bottom of this box compatible with values extracted from Baldner et al. (2009) and shown in Fig. 5. Two complementary effects are visible in the simulations: a slow reduction of the turbulence by the deeper magnetic field in the lower part of the box and a direct effect of the magnetic field in the last 500 km just below the surface (see also Piau et al. (2011)). These simulations agree reasonably with what we observe in the present study, of course the effect is amplified at the near surface in acoustic mode frequencies due to the travel time of the modes.

## 5. Discussion on the physical mechanism behind the QBP

Seismic signatures of the 11 and 2 yr cycle in  $p$ -mode frequency shifts might provide a deeper insight on the mechanism behind the cyclic behavior of solar activity. In this section we will interpret our observational findings to shed light on the mechanism behind the 2 yr signal.

### 5.1. Second dynamo mechanism

In agreement with earlier findings we note that the size of the shift, over the 11 yr cycle, undergoes a sudden and strong enhancement at  $\approx 200$  km below the photosphere, while over the same range of depths we found a reduced gain over the two year cycle. Because of this, some authors invoked the ac-

tion of a second dynamo mechanism (Fletcher et al. 2010; Broomhall et al. 2012) due to the subsurface rotational shear extending 5% below the solar surface (Schou et al. 1998). In Sec 3.4 we have shown that the origin and the behavior of the shift for both periodic components of solar magnetic activity in the subsurface layers is due to the sudden and stronger decrease of  $\beta$ . Therefore we do not visualize a need to invoke a further dynamo mechanism to explain the origin of the shift induced by the 2 yr cycle. Moreover the latitudinal dependence of the size of the shift does not differ over the two cycles and the 11 yr envelope clearly modulates the amplitude of the 2 yr signal at all latitudes, suggesting that the two periodicities are intimately coupled. Thus our seismic analysis do not provide observational evidences in favor of a different and separate mechanism from the main dynamo behind the origin of the 2 yr cycle. We also want to stress out that our analysis do not exclude the possibility that the strong rotational shear layer might have a role in the generation of toroidal fields (Pipin & Kosovichev 2011), since our analysis indicates that the dynamo independent of its location is behind both component of solar magnetic activity.

### 5.2. Instability of magnetic Rossby waves

The instability of magnetic Rossby waves in the tachocline might enhance the 2 yr periodicity when the magnetic field strength is greater than  $10^5$  G (Zaqarashvili et al. 2010). Such strong magnetic fields are difficult to exist in the tachocline. In fact using splitting of modes with their lower turning points around the base of the convective zone gave an upper limit of 0.3 MG (Basu 1997), in good agreement with similar upper values of 0.3-0.4 MG found by other investigators (Antia et al. 2000). Furthermore it is still an ongoing investigation how the magnetic Rossby waves vary with latitude in slow rotator stars. In order to fit with our results, it should be proven that the Rossby waves are smoothly redistributed along the latitudes with a maximum at low latitude and the poloidal wave number should be such that no nodes will rise from the equator towards the polar regions.

### 5.3. Flip-Flop cycle

It has been noticed that the biggest active regions tend to appear always at similar longitudes, which are called active longitudes. These are persistent over many cycles, but it can suddenly shift by  $180^\circ$



to the other side of the star (Berdyugina & Usoskin 2003). This phenomenon is known as flip-flop cycle (Jetsu et al. 1991) and it seems to be rather common in stars (Berdyugina & Tuominen 1998, 2002). The origin of the flip-flop cycle is not yet fully understood, but it could be explained as the result of the excitation of a global non axisymmetric (quadrupole) dynamo mode (Moss et al. 1995; Tuominen et al. 2002; Moss 2004). Such dynamo configuration is plausible to exist in the Sun along with the dipole as inferred by solar dynamo models (Moss & Brooke 2000). The relative strengths of the two dynamo modes should define the amplitudes of the observed cycles. Within this formalism it is also predicted that the amplitude of the secondary cycle, in general, is expected to have lower amplitude, as part of the energy is transferred from the primary magnetic configuration (dipolar) to the secondary one (quadrupolar). This feature agrees well with our findings, as we have shown that the secondary cycle in the Sun is an additive contribution to the main cycle, whose signal strength is rather weak. The period of the oscillations of the axisymmetric mode should, instead, define the lengths of the observed cycles. Therefore the full flip flop cycle is expected to have the same length as the axisymmetric mode (Berdyugina & Tuominen 2002). In the Sun the major spot activity alternates the active longitudes in about 1.8-1.9 years and on average it has been observed to make 6 switches of the active longitude during the 11 yr sunspot cycle. These values have been obtained by the analysis of solar cycle 18 up to 22 whose lengths were shorter than 11 yr. Our findings seems to fit well with predictions and observations of flip-flop cycles. We found a significant periodicity at  $\approx 2$  years, a bit higher than the usual flip-flop findings, but solar cycle 23 lasted longer than usual (about 12.6 years). We, then, might expect that all periodicities between  $1.5 \text{ yr} \leq T \leq 4 \text{ yr}$  (corresponding to individual periods of one longitude's dominance) might be seen as the visible manifestation of the same physical mechanism. Recently some other authors also concluded that the non-constant period length is the manifestation of a unique quasi-biennial cycle (Vecchio & Carbone 2008; Vecchio et al. 2009). Furthermore the magnitude of the shift increases towards equatorial latitudes over both periodic components of solar magnetic activity and this feature comes up naturally within this formalism.

## 6. Conclusion and further perspective

The analysis of the QBP signal in  $\ell = 0$  to 120 acoustic mode frequency shifts shows that this signal is persistent on the whole solar cycle 23 and the ongoing cycle 24. The significant reduction in the QBP signal strength over the ascending phase of solar cycle 24 might be interpreted as signatures of a weaker sub surface magnetic field. The current dynamo models struggle to predict the basic parameters such as duration and strength of the activity cycle and therefore the idea to use acoustic waves as precursor of solar cycle is fascinating. To reach this aim, it will be fundamental to identify the physical mechanism behind it. Our detailed analysis seems to suggest that the QBP might be the result of the beating between different dynamo modes.

Evidences of North-South asymmetry have led some authors to speculate that a significant quadrupolar component is still present (Pulkkinen et al. 1999), but some others stated that since the end of the Maunder Minimum the solar field has been dipolar (Tobias 1996, 1998). If the QBP signal is confirmed to be the result of the beating between different dynamo modes, then this work provides further evidence in favor of the existence of a quadrupolar component in the Sun. It will be extremely important, therefore, to look for signatures of the quadrupolar magnetic dynamo configuration. It is not a simple task, but within this context the investigation of the seismic properties of the QBP signal might play a key role. For example some authors found the periodicity from the northern hemisphere to differ from the one in the south hemisphere (Vecchio & Carbone 2008; Vecchio et al. 2009; Berdyugina & Usoskin 2003). It will be worth to check if the analysis of  $p$ -mode frequency shift or other  $p$ -mode parameters in the two hemisphere might also spot asymmetries. Solar cycle 24 could be a good candidate to look for asymmetry. Infact we have already shown the signatures of the 2 yr cycle over its ascending phase. Furthermore it will be equally important to investigate magnetic activity on other solar type stars using long term data provided, for example, by asteroseismology missions (such as COROT, Kepler). The availability of a sample of solar analogues selected at different stages of their evolution will give us the opportunity to infer accurate relations between activity quantities, such as the length and amplitude of cycles and stellar properties such as rotation, age and convective envelope depth. Solar and stellar ac-

tivity requires more systematic and detailed studies to advance, observationally and theoretically, our understanding of the dynamo.

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